In the film, humans, animals, and machines come together in solidarity
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Driver-less Vision: Learning to See the Way Cars Do

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Recent developments in driverless technologies have brought discussions around urban environments to the forefront. While developing the actual vehicles, major players such as Waymo (Google), Volkswagen, or Uber are equally invested in envisioning the future of cities. Yet, the proposed scenarios tend to emphasize consensual solutions in which idealized images of the streets seamlessly integrate driverless technology. Avoiding the immediate future, these visions focus on a distant time in which the technology has been hegemonically deployed: Only driverless cars circulate while humans, city infrastructure, and autonomous vehicles have learned to live together.[1]

1. Future scenarios tend to focus their predictions on how driverless cars combined with a sharing economy could reduce drastically the total amount of cars and on the implications of this reduction in urban environments. Brandon Schoettle and Michael Sivak of the University of Michigan Transportation Research Institute foresee a 43% contraction. (Brandon Schoettle and Michael Sivak, "Potential Impact of Self-driving Vehicles on Household Vehicle Demand and Usage," http://www.driverlesstransportation.com/wp-content/uploads/2015/02/UMTRI-2015-3.pdf ([accessed February 2017]). Sebastian Thrun, a computer scientist at Stanford University and former leader of Google's driverless project predicts a 70% ; see "If Autonomous Vehicles Rule the World," *The Economist*, http://worldif.economist.com/article/12123/horseless-driverless (accessed February 2017)). Matthew Claudel and Carlo Ratti anticipate an 80% reduction (Matthew Claudel and Carlo Ratti, "Full Speed Ahead: How the Driverless Car Could Transform Cities," Mckinsey.com, http://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/full-speed-ahead-how-the-driverless-car-could-transform-cities, accessed January 2017). Luis Martínez of the International Transport Forum expects a 90% decline in his study of Lisbon mobility (Luis Martínez, "Urban Mobility System Upgrade: How Shared Self-driving Cars Could Change City Traffic," CITF, OECD, http://www.itf-oecd.org/sites/default/files/docs/15cpb_self-drivingcars.pdf, accessed January 2017). In a similar exercise, Dan Fagnant of the University of Utah forecasts a 90% decline for the city of Austin (Daniel James Fagnant, "Future of Fully Automated Vehicles: Opportunities for Vehicle- and Ride-sharing, with Cost and Emission Savings," Ph.D. diss., University of Texas, https://repositories.lib.utexas.edu/bitstream/handle/2152/25932/FAGNANT-DISSERTATION-2014.pdf?sequence=1 (accessed February 2017). All of these hypotheses operate in a distant future when the technology has been fully implemented. IEEE predicts up to 75% of vehicles will be autonomous in

This paper argues instead that the conflicts untapped by the new technology's disruptive effects will trigger the most meaningful transformations of the city and that these changes they will happen in the near future. The fast deployment of driverless technology does not preclude a specific urban solution. Rather, it requires our imagining how the cohabitation of humans and cars is going to be discussed. Our hypothesis entails that, in the short term, the urban realm will be the place where the negotiation will take place and that the differences in the ways cars and humans sense the city will define the terms of the discussion.

After successful deployment of autonomous vehicles in close circuits and major non-urban areas, the city has become the ultimate frontier for driverless technologies. Personal rapid transit systems (PRT) operating in closed systems like the self-driving pods in Heathrow Airport have been successfully running since the end of yhe last century.[2]

Adaptive Cruise Control, Automatic Emergency Braking, or Automatic Parking are widely available in commercial cars. Tesla, BMW, Infiniti, and Mercedes-Benz offer models with Automatic Lane Keeping that guides the car through freeways and rural roads without relying on the driver's hands, eyes, or judgment.[3] Yet the city seems to resist the wave of autonomous cars. Several reasons explain why. Urban environments multiply the chances of unforeseen events and dramatically increase the amount of sensorial information required to make driving decisions. The quality and amount of data is directly proportional to the price of the technology and to the chances of the car's successfully resolving difficult situations. It also is inversely proportional to the car's processing and decision-making speed.

2040 and IHS forecasts that almost all of the vehicles in use will be driverless by 2050; see IEEE, "Look Ma, No Hands!," http://www.ieee.org/about/news/2012/5september_2_2012.html (accessed February 2017) and IHS, "Emerging Technologies: Autonomous Cars—Not If, But When," http://www.ihssupplierinsight.com/_assets/sampledownloads/auto-tech-report-emerging-tech-autonomous-car-2013-sample_1404310053.pdf (accessed February 2017).

2. Personal rapid transit (PRT) was developed in the 1950s as a more economical response to the conventional metro system supported by the Urban Mass Transportation Administration (UMTA). Originally they had similar capacity to cars but as they evolved into bigger vehicles they lost these advantages. As a result only one PRT was built, in Morgantown, WV (USA). It has been operating successfully since then. We can position Heathrow's pods, the Sky Cube in Suncheon (Korea), or Masdar Abu Dabhi pods as their latest implementations of this technology.

3. In January 2014, SAE International (Society of Automotive Engineers) issued a classification system defining six levels of automation, spanning from no automation to full automation (0 to 5), with the goal of simplifying communication and collaboration among the different agents involved. The classification is based on the amount of driver intervention and attention required instead of the vehicular technological devices. The characterization sets a crucial distinction between level 2, where the human driver operates part of the dynamic driving task, and level 3, where the automated driving system carries out all dynamic driving task. SAE., "Automated Driving. : Levels of Automation Are Defined in New SAE International Standard J3016"," https://www.sae.org/misc/pdfs/automated_driving.pdf (accessed February 2017)). Later in 2014, Navya launched a self-driving vehicle (level 5) which has been performing successfully in different closed environments from Switzerland to France, the United States,

The equilibrium between these two opposed parameters defines different approaches to the driverless cars.[4] Eventually, it will also define how the streetscape needs to change to accommodate the cohabitation of autonomous vehicles, regular cars, pedestrians, and other forms of transportation.

The presence of self-driving cars in urban environments also challenges accepted notions of safety. Accidents involving self-driving cars are well documented. Google issued a public report monthly until November 2016. Tesla and Uber are more secretive, but their accidents tend to become media events.[5]

England, and Singapore. Arma, their latest carrier, is operating trials under fixed routes in urban scenarios. The shuttle can transport up to 15 passengers and drive up to 45 km/h. Other major players have been testing vehicles in closed environments and on public roads under special circumstances. When driven on public roads, the cars require at least one person to monitor the action and assume control if needed. Some of the more popular testing programmes involve companies such as Waymo (Google), Tesla, or Uber. Google has been testing their cars since 2009 on freeways and testing grounds. In 2012, they shifted to the city streets, identifying the need to do tests in more complex environments. In their latest published monthly report, in November 2016, their vehicles operated 65% of the time on autonomous mode. Along the lifespan of the programme they have accumulated more than 2 million self-driven miles.(Waymo, "Journey," https://waymo.com/journey/ [accessed February 2017]).

Tesla started deploying their Autopilot system in 2014, with a level 2 automated vehicle. In October 2016, Tesla announced that their vehicles have all the necessary hardware to be fully autonomous (level 5 capabilities). However, as they clearly state, its functionality depends on extensive software validation and regulatory approval. They currently offered multiple capacities such as adaptive cruise control or autosteer. Initially, the systems could only be deployed on specific highways but at as of February 2017, they also perform in some urban situations. (Tesla, "Full Self-Driving Capability," https://www.tesla.com/autopilot [accessed February 2017]).Uber joined the race in 2016. Their controversial programme offered, right after nuTonomy's pilot scheme, to carry fare-paying passengers in cars that have a high level of autonomy. The vehicles deploying this service have two employees in the front seats to monitor and take control in case of problems.

4. Tesla's current sensing system arrays eight cameras that provide 360 degrees of visibility with a range of 250 m. Twelve ultrasonic sensors and a forward-facing radar complement and strengthen the system. However, Waymo and most of the other competitors follow a different approach. (Tesla, "Advanced Sensor Coverage," https://www.tesla.com/autopilot [accessed February 2017]).Waymo's most advanced vehicle, a Chrysler Pacifica Hybrid minivan customised with different self-driving sensors, relies primarily on LiDAR technology. It has three LiDAR sensors, eight vision modules comprising multiples sensors and a complex radar system to complement it. (Waymo team, "Introducing Waymo's Suite of Custom-built, Self-driving Hardware," Medium, https://medium.com/waymo/introducing-waymos-suite-of-custom-built-self-driving-hardware-c47d1714563 [accessed February 2017]).

5. Tesla's fatal accident occurred on 7 May 2016 in Willston, Florida, while a Tesla Model Selectric car was engaged in Autopilot mode; see Anjali Singhvi and Karl Russell, "Inside the Self-Driving Tesla Fatal Accident," *New York Times*, 1 July 2016, https://www.nytimes.com/interactive/2016/07/01/business/inside-tesla-accident.html

The majority of these events involve single vehicles or collisions between two or more vehicles. Urban environments increase the chances of accidents involving pedestrians and other forms of non-vehicular traffic. The ethical implications of this scenario have been popularized by MIT's interactive online test, Moral Machine.[6]

Self-driving technologies imply a transfer of accountability to the algorithms that guide the vehicle. Most legal experts predict a trend towards increased manufacturer liability with increased use of automation. Major players such as Volvo, Google, or Mercedes already supported this solution in 2015. Car manufacturers will accept insurance liabilities after full automatization (level 5) is a reality.[7] But safety goes beyond the insurance conundrum. In *Aramis, or the Love of Technology*, Bruno Latour proves how the success of a new technology is deeply connected with the perceived dangers it entails.[8]

To share the streets with cars driven by computers shakes collective notions of acceptable risk. The technology needs to prove trustworthy. And trust, in this cases, results from a combination of scientific evidence, storytelling, and public demonstrations constructed by the engineers, economies, and populations involved in their development. When common agreements regarding trust and responsibility shift, the way we will live together needs to be settled, again.[9]

(accessed February 2017). Uber's most recent accident happened on 24 March 2017. Although they were not accused for being responsible of the accident, they temporarily suspended their programmes in their three testing locations: Arizona, San Francisco, and Pittsburgh. See Mike Isaac, "Uber Suspends Tests of Self-Driving Vehicles After Arizona Crash," *New York Times*, 25 March 2017, https://www.nytimes.com/2017/03/25/business/uber-suspends-tests-of-self-driving-vehicles-after-arizona-crash.html.

6. Iyad Rahwan, Jean-Francois Bonnefon, and Azim Shariff, "Moral Machine: Human Perspectives on Machine Ethics," http://moralmachine.mit.edu/ (accessed January 2017).

7. Kirsten Korosec, "Volvo CEO: We Will Accept All Liability When Our Cars Are in Autonomous Mode," *Fortune*, 7 October 2015, http://fortune.com/2015/10/07/volvo-liability-self-driving-cars/ (accessed February 2017), and Bill Whitaker, "Hands off the Wheel," *Sixty Minutes*, CBS, http://www.cbsnews.com/news/self-driving-cars-google-mercedes-benz-60-minutes/ (accessed February 2017).

8. Bruno Latour, *Aramis, or the Love of Technology* (Cambridge, MA: Harvard University Press, 1996).

9. Charles Perrow analyzes the social side of technological risk. He argues that accidents are normal events in complex systems; they are the predetermined consequences of the way we launch industrial ventures. He believes that the conventional engineering approach to ensuring safety, building in more warnings and safeguards, is inadequate because complex systems assure failure. Charles Perrow, *Normal Accidents: Living with High-Risk Technologies*. (Princeton, NJ: Princeton University Press, 1999). Hod Lipson, professor at Columbia University and co-author of *Driverless, Intelligent Cars and the Road Ahead*, advises that the Department of Transportation should define a safety standard based on statistical goals, not specific technologies. They should specify how safe a car needs to be before it can drive itself, and then step out of the way.(Cited in Russ Mitchell, "Why the Driverless Car Industry Is Happy (So Far) with Trump's Pick for Transportation Secretary," Los Angeles Times, 5 December 2016, http://www.latimes.com/business/autos/la-fi-hy-chao-trump-driverless-20161205-story.html.

If dense urban environments intensify the conflicts between technology, ethics, economy, and collective safety, the realm of sensing renders the conflicts public. The arrival of autonomous vehicles entails the emergence of a new type of gaze that requires the negotiation of existing codes. Currently, human perception defines the visual and sonic stimuli that regulates urban traffic. The transfer of information has been designed, with few exceptions, to be effective for human vision and in some cases for human audition. Driverless sensors struggle with these logics; e.g., redundancy, used to capture drivers' attention, often produces a confusing cacophony for autonomous vehicles. Dirtiness on the road graphics, misallocations of signage, consecutive but contradictory traffic signs, or even the lack of proper standardization of traffic signs and markings are the reasons behind some of the most notorious incidents involving autonomous vehicles.[10]

Assuming that driverless cars will adapt to these conditions implies a double contradiction. It forgets the history of transformations of streetscape associated with the changes in vehicular technologies.[11] But more importantly, it ignores

10. Several relevant figures in the field such as Elon Musk from Tesla, Lex Kerssemakers, the North America Volvo CEO, and Christoph Mertz, a research scientist at Carnegie Mellon University, have pointed out the problem of faded lanes in the current development of the technology. Paul Carlson, from Texas A&M University, aims for consistency in signage along American roads in order to accommodate automation favorably. The agency Reuters also points out that the lack of standardization in the US compared to most European countries, which follow the Vienna Convention on Road Signs and Signals, causes a big problem. At the same time several researchers at Sookmyung Women's University and Yonsei University in Seoul are focusing on how current automated sign recognition systems detect irrelevant signs placed along roads. This problematic cacophony is dramatically amplified in urban scenarios. See Alexandria Sage, "Where's the Lane? Self-driving Cars Confused by Shabby U.S. Roadways," Reuters, http://www.reuters.com/article/us-autos-autonomous-infrastructure-insig-idUSKCN0WX131 (accessed December 2016); Andrew Ng and Yuanquin Lin. "Self-Driving Cars Won't Work Until We Change Our Roads—And Attitudes," *Wired* https://www.wired.com/2016/03/self-driving-cars-wont-work-change-roads-attitudes/ (accesed December 2016); and Signe Brewster, "Researchers Teach Self-driving Cars to 'See' Better at Night," *Science*, http://www.sciencemag.org/news/2017/03/researchers-teach-self-driving-cars-see-better-night (accessed March 2017).

11. The relationship between the transformations of the streetscape and the arrival of new vehicular technologies also places driverless cars at the center of the history of architecture. Since its inception, the car has often played a central role in architects' urban visions. The precepts of the Athens Charter and the images of the Ville Radieuse were an explicit responses to the safety and functional issues associated with the popularization of car. Its implementation, with different degrees of success, during the post-war reconstruction of Europe and the global explosion of suburban sprawl, fueled architectural controversies that questioned the role of cars in the definition of urban environments. Ian Nairn's *Outrage* (1955), Robin Boyd's *Australian Ugliness* (1960), Appleyard, Randolph Myer, and Lynch's *The View from the Road* (1964), Peter Blake's *God's Own Junkyard* (1965), Reyner Banham's *Los Angeles: The Architecture of Four Ecologies* (1971), Venturi, Scott-Brown and Izenour's *Learning from Las Vegas* (1973), and Alison and Peter Smithson's *AS IN DS: An Eye on the Road* (1983) are not only some well-known examples of these debates; they also show how the topic lost traction in architecture debates at the end of the last century.

the fact that self-driving cars construct images that are barely comparable to human perception.[12] Driverless cars take in real-time data through different on-board sensors. Although there is not an industry standard yet, certain trends are ubiquitous. The vehicles use a combination of radars, cameras, ultrasonic sensors, and LiDAR scanners to get immediate information from the external environment.[13] The resulting perception differs greatly from a human one. Driverless cars do not capture environmental sound. Colour rarely plays a role in the way they map the city. And, with various degrees of resolution, their sensors cover 360 degrees around the vehicle.

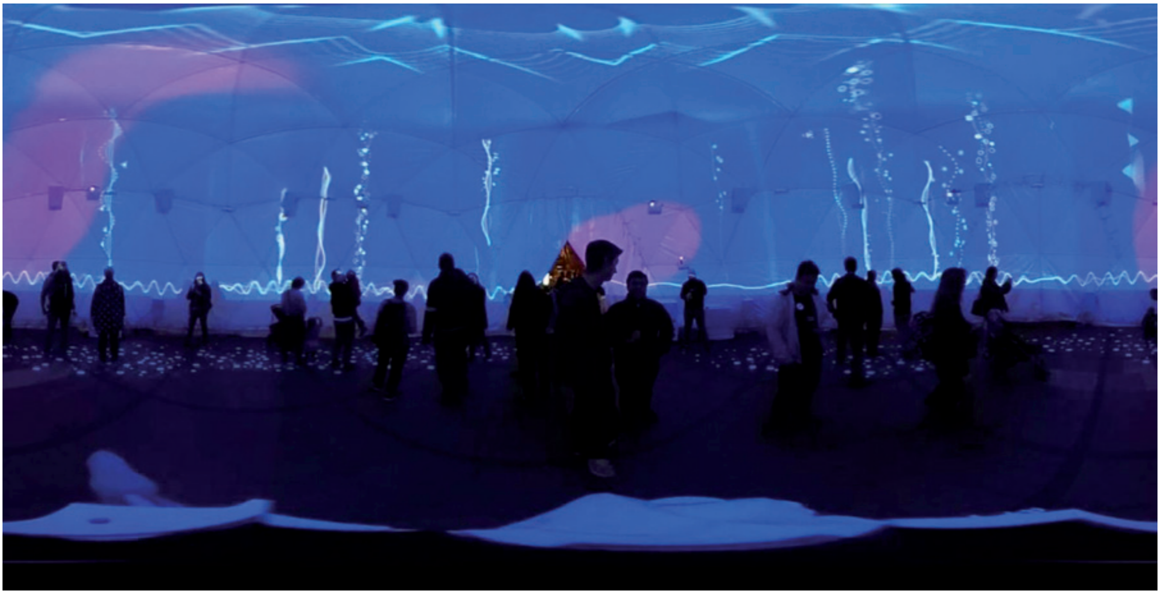
At the same time, car sensors and human senses share a logic of specialization. The human sense of hearing tends to recognize exceptional and abrupt changes in the sonic landscape—a siren, a claxon, a change in the sound of the engine. Even if human peripheral vision operates in a similar fashion, attention is essential for eyesight. Human vision requires continuity and focusses on subtle changes. Thus fog or darkness decrease the eye's ability to discern difference and decrease its effectivity. Similarly, the way self-driving cars' sensors function defines their potentials and limitations. Some sensors detect the relative speed of objects in close range while others capture the reflectivity of static objects far away. Some are able to construct detailed 3D models of objects no farther than a meter away while others are indispensable for pattern recognition. Human drivers combine eyesight and hearing to make decisions and driverless cars' algorithms use information from multiple sensors in their decision-making processes. Yet, autonomous vehicles' capacity for storing the information their sensors capture makes a big difference. As each of the four types of sensors in a driverless car captures the area they circulate, they also produce a medium-specific map of their environment.

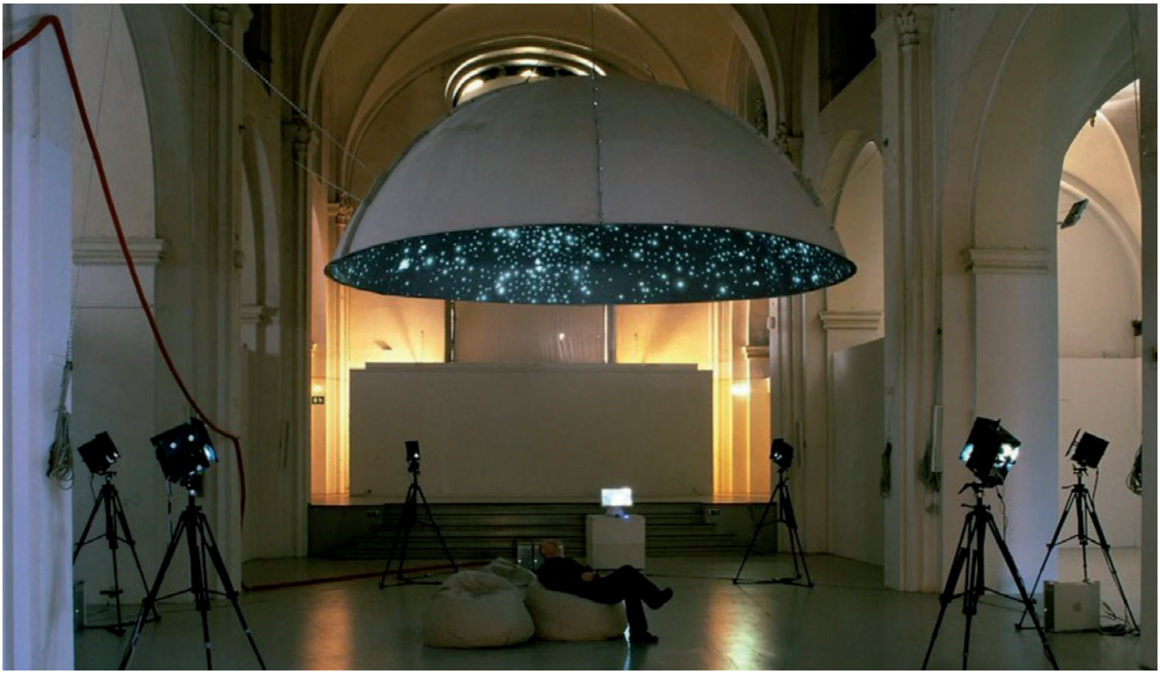
Radars are object-detection systems that use radio waves to determine the range, angle, or velocity of objects. They have good range but low resolution, especially when compared to ultrasonic sensors and LiDAR scanners. They are good at near-proximity detection but less effective than sonar. They work equally well in light and dark conditions and perform through fog, rain, and snow. While they are very effective at determining relative speed of traffic, they do not differentiate colour or contrast, rendering them useless for optical pattern recognition. They are critical to monitoring the speed of other vehicles and objects surrounding the self-driving car. They detect movement in the city and are able to construct relational maps capturing sections of the electromagnetic spectrum.

Ultrasonic sensors are object-detection systems that emit ultrasonic sound waves and detect their return to define distance. They offer a very poor range, but they are extraordinarily effective in very-near-range three-dimensional mapping. Compared to radio waves, sound waves are slow. Thus, differences of less than a centimetre are detectable. They work regardless of light levels and also perform well in conditions of snow, fog, and rain. They do not provide any

12. Uber's arrival is linked to the famous Google lawsuit against Uber that position LiDAR technology at the centre of the dispute. Again, this legal battle locates the discussion of the car's ability to see the world. See Alex Davies, "Google's Lawsuit Against Uber Revolves Around Frickin' Lasers," *Wired,* https://www.wired.com/2017/02/googles-lawsuit-uber-revolves-around-frickin-lasers/ (accessed March 2017).

13. For a detailed list of the the onboard sensors used by different self-driving car brands, see footnote 4.





Up to the left:
360 immersive projection in the dolby dome for Vivid 2016 Festival

Up to the right:
Black Shoals Dome exhibited at Nikolaj Copenhagen Contemporary Art Centre

On the left:
Still from "Where the City can See" a LiDAR film by Liam Young

colour or contrast or allow optical character recognition, but they are extremely useful to determine speed. They are essential to for automatic parking and to avoid low-speed collisions. They construct detailed 3D maps of the temporary arrangement of objects in the proximity of the car.

LiDARs (Light Detection and Ranging) are surveying technologies that measure distance by illuminating a target with a laser light. They are currently the most extended object-detection technology for autonomous vehicles. They generate extremely accurate representations of the car's surroundings but fail to perform in short distances. They cannot detect colour or contrast, cannot provide optical character recognition capabilities, nor they are effective for real-time speed monitoring. Light conditions do not decrease their functionality, but snow, fog, rain, and dust particles in the air do. Due to their use of light spectrum wavelengths, LiDAR scanners can sense small elements floating in the atmosphere. They produce maps of quality of air quality.

RGB and infrared cameras are devices that record visual images. They have very high resolution and operate better in long distances than in close proximity. They can determine speed, but not at the level of accuracy of radar. They can discern colour and contrast but underperform in very bright conditions and also as light levels fade. Cameras are key for the car's optical-character recognition software and are *de facto* surveillance systems.

This proliferation of sensors in the environment is a defining factor of the imminent urban milieu. Environmental sensors connected to cars distribute instant remote sensing, enabling the constant flow of information on the urban environment while at the same time radicalizing issues of privacy, access, and control. They simultaneously react to and change the urban pattern, generating an unprecedented environmental consciousness. The resulting image of the city cannot differ more from human perception. It is a combination of sections of the electromagnetic spectrum, detailed 3D models around cars, detailed maps of air pollution, and an interconnected surveillance system. It is not the city as we see it.

And yet interconnected sensors can create a new common, a ubiquitous, global sensorium that obliterates further the distinction between nature and artifice. While the city is managed by non-human agencies, it continues to be designed around the assumption of a benign human-centered system. Engaging citizens in this new sensorial environment makes them aware of the necessity of a new sensorial social contract.[14] It embeds the judgment of society, as a whole, in the sensorial governance of societal outcomes. The city is therefore the space where we can gain mutual confidence trust, generating the necessary relationship for coming scenarios of coexistence. In other words, driverless vision isn't just about cars, rather it is more akin to the interaction between a government and a governed citizenry. Modern government is the outcome of an implicit agreement—or social contract—between the ruled and their rulers, aimed at fulfilling the general will of citizens.

14. "Algorithmic Social Contract" is a termed coined by MIT professor Iyad Rahwan and develops the idea that by understanding the priorities and values of the public, we could train machines to behave in ways that the society would consider ethical. See Iyad Rahwan, "Society-in-the-Loop: Programming the Algorithmic Social Contract," www.medium.com https://medium.com/mit-media-lab/society-in-the-loop-54ffd71cd802 (accessed March 2017).